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STATION BLACKOUT AT NUCLEAR POWER PLANTS RADIOLOGICAL IMPLICATIONS FOR NUCLEAR WAR

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ABSTRACT

We review recent work on station blackout and explore its radiological implications for a nuclear war scenario. Our major conclusion is that the effects of radiation from many nuclear weapon detonations in a nuclear war would swamp those from possible reactor accidents that result from station blackout.

CONTENTS

INTRODUCTION

Electric power is critical to the safe operation and shutdown of nuclear reactors. Electricity supplies the power for the reactor instrument and control systems. These systems are the central nervous system that controls the plants' eyes, ears and muscles. Station blackout is the loss of AC off-site electric power coupled with a failure of the emergency on-site AC power sources. This could result in core damage and the release of some of the large fission radioisotope inventory residing in the core (Ref. 1). A large scale nuclear war would probably result in the loss of most of the power grids in the nation for an extended time period. In this paper we examine some radiological implications of this possibility. Our discussion is restricted to potential radiological releases from reactors that result directly from station blackout only. We do not consider here releases resulting from other pathways (accident sequences other than station blackout or direct attacks on the reactors).

Our approach is to draw upon recent work on the station blackout problem (Refs. 1, 2, 3). This work assumes the frequency of off-site power loss to reactors follows the operating experience record in the United States of the past two decades. We shall first attempt to summarize the results of this work, and then explore the implications of an extended failure of the national power grid following a nuclear war. We also speculate on the possibility of direct damage to the emergency electric power supply systems at the reactor site.

Background

An important distinction between nuclear electric power reactors and other types of electric generating plants arises when the plant is shut down. When an oil, gas or coal fired plant is shutdown, the generation of heat energy stops almost immediately. When a nuclear reactor is shut down by the insertion into the core of neutron absorbing control rods, the fission chain reaction is stopped essentially immediately. However, the production of heat energy does not stop. About seven percent of the energy released in nuclear fission comes from the radioactive decay over time of the fission products that reside within the fuel elements. A typical contemporary power plant produces about 3000 megawatts of thermal energy, from which 1000 megawatts of electric power is generated. Immediately following the shutdown of such reactors, there is initially about 200 megawatts being released in the reactor core in the form of decay heat. This large amount of heat generation must be removed to prevent the core from heating up and possibly producing core damage. The source term of any radioactive inventory release to the atmosphere that could eminate from a damaged core depends upon the reactor design, its history of operation, and the nature of the containment. Heat build-up in the reactor containment building also must be limited to maintain containment and prevent radioactive releases.

The mix of the hundreds of different kinds of radioisotopes residing in the reactor have half-lives that range from fractions of a second to billions of years. The overall time rate of decay of this mix for the first week follows roughly a $t^{-0.25}$ dependence. At 24 hours after shutdown, the decay heat generation is down by about a factor of ten (from 200 to about 20 megawatts), and at the end of a week it is further reduced by about a factor of 4 to the order of 5 megawatts.

If we relate heat produced to the reactor core cooling pumps that are powered electrically, removing 3000 megawatts of heat from the core of a pressurized water reactor (PWR) requires about 400,000 gallons per minute (gpm) of water coolant passing through the core. Assuming the same ΔT in the primary coolant loop during shutdown, then 200 megawatts requires about 27,000 gpm, and 20 megawatts about 2700 gpm. If the heat generation decreases to below 5 megawatts and the reactor vessel is adequately filled with water, then the need for coolant pump operation decreases as well. After a reactor scram, most PWR's can transfer decay heat via natural circulation from the core to the secondary coolant system so that turbine driven auxiliary feedwater systems are adequate to remove heat. However, with our present state of knowledge, it should be assumed that even for several weeks after shutdown with no AC power, that the core will melt if adequate cooling is not provided. Personnel on site can do many things to insure such cooling is available to avoid this (using fire diesels, fire trucks, venting of containment, etc.). However, if the plant is not staffed (a possible scenario in a nuclear war situation) these backup cooling approaches may not be operable. One can presume in an extended station blackout that if there are no fuel sources available (oil, gas), the core will melt.

A 1975 reactor safety study (Ref. 4) indicated that station blackout is an important contributor to the risk of nuclear reactor accidents. Station blackout was officially designated as Unresolved Safety Issue A-44 by the U.S. Nuclear Regulatory Commission (NRC) in 1979. Several NRC sponsored studies have been carried out since then as part of a Task Action Plan (TAP A-44) issued in July, 1980. This work has now evolved into a proposed NRC safety regulation (currently under review) that specifies that commercial nuclear power plants have the capacity to safely handle station blackout (power losses) of either 4 or 8 hours duration. In addition, a minimum level of diesel generator reliability would be required (0.95 per demand). This proposed regulation is concerned with historical off-site power loss durations and does not address the problem of long term (1 or 2 week) losses that are probable for some nuclear war scenarios (consideration of acts of war are not the pervue of the Nuclear Regulatory Commission).

An analysis of the risk from station blackout events involves an assessment of (a) the likelihood and duration of loss of off-site power events, (b) the reliability of on-site emergency power, and (c) the potential for core meltdown after loss of all electric power.

History of Off-Site Power Loss

Recently, Harvey Wyckoff of the Nuclear Safety Analysis Center (NSAC) at the Electric Power Research Institute (EPRI) published a survey of the history of off-site power loss in the United States from 1968 through 1983 (Ref. 2). His survey covered approximately 90 nuclear power reactors located at 65 sites. The significant findings of Wyckoff's study are:

(a) There were 55 losses of all off-site power in 665 site-years (Site-years is the number of years a reactor was operating starting with initial licensing) yielding a figure of 0.083 events per site-year for losses of any duration. For losses of longer than 2 hours the value is 0.017 events per site year, and for longer than 4 hours it is 0.008.

(b) 38 of 65 sites never lost off-site power (58%).

(c) The median duration of all losses was 30 minutes.

(d) 7 of 65 sites had a loss longer than 2 hours (10%).

(e) The longest event was 8 hours and 54 minutes.

(f) There were only 4 events longer than 30 minutes in 1983 through 1985. No events occurred in 1984.

(g) 25% of all events occurred at 2 sites. One site has been free of problems for 8 years after redesigning the high voltage transmission system. The other site is in the process of expanding its switchyard to correct it's problems.

(h) Events have been caused by on-site failures, grid blackouts, and weather related incidents. Weather events (such as thunderstorms, and tornados, hurricanes) have a potential for longer term outages. The longest outage was 9 hours at the Pilgrim Plant in 1978, and was caused by a storm coating the switchyard with ice and salt. The second longest was 6.5 hours at Indian Point in 1977, and was initiated by lightning leading to grid failure. A 5 hour outage at Millstone in 1976 was caused by a hurricane coating the switchyard with salt.

In summary, operating experience shows that overall loss of off-site power occurred at the rate of approximately 0.1 events per site year.

Reliability of On-Site Emergency Electric Power

The emergency power systems at every U.S. reactor site provide a backup power supply to the off-site power systems. These are generally in the form of two or more diesel generators although gas turbine generators and hydroelectric power or steam generators are used at some sites. At most sites where dual reactors exist, a fifth "swing" diesel generator in addition to the two dedicated diesels for each reactor provides added reliability. At most sites, the output of one diesel generator is sufficient to meet AC power requirements for an off-site power loss event. Many plants also have low pressure water diesel pumps that can provide service cooling water in the event of station blackout.

Since TMI-2, U.S. nuclear power plants are required to have at least one decay heat removal system available that is AC power-independent. At most plants, this system depends on station battery power and on steam. Battery power will last in the range of 4 to 10 hours without recharging by the deisels depending upon the specifics of plant design. It is generally accepted that if AC power was unavailable for a prolonged period (longer than 4 to 10 hours) uncommon measures would be required, but even then there is the possibility of sizeable releases. Plants that have totally independent means of supplying water to the core and of removing decay heat, such as diesel driven pumps, would be able to cope longer without AC power. Also, steps such as venting the containment prior to core melt to prevent uncontrolled containment failure, could greatly reduce release rates and total amounts. In any event, one could expect that after a day or more, containments may fail. On the other hand, after this length of time, radioactive releases would be smaller since much of the released fission products would have settled within the containment.

Substantial operating experience data have yielded information on the reliability of emergency diesel generators (EDGs) (Ref. 3). Analysis of this experience has shown that, on average, diesel generators failed to start, load, or continue running approximately 1.4% of the time or 98.6% average reliability per demand. A median of estimated repair time following a diesel generator failure is considered to be about 8 hours (in non-emergency situations).

For longer term losses of off-site power, the availability of even one EDG at a site should provide the means to prevent core damage or radioactive releases. Hence the reliability of all EDGs at a site as an entity is an important parameter. Out of a total of 144 site years in the NSAC survey (overall average reliability of 98%), only 12 site years had a reliability less than 95%. The lowest was 89%.

The combining of independent diesel generator failure probabilities and common cause terms to predict the probability that no on-site power would be available when needed is involved. One of the most complete developments of this is NUREG-1032 (Ref. 1). Assuming nuclear units maintain the required EDG independent reliability of 95% and that one EDG per nuclear unit is adequate to remove decay heat upon a loss of off-site power, the probability that no EDG will start will fall between 1.5×10^{-3} and 5×10^{-3} (Ref. 3).

In summary, if there is an off-site power loss, the probability of a failure of the on-site power sources at most plants under normal peace-time conditions will be in the range of 1.5×10^{-3} to 5×10^{-3}. If we combine this with the earlier estimate of 10^{-1} for the probability per site-year of an off-site power loss, we arrive at an estimated range of frequency in peace-time of station-blackout per year per site of 1.5×10^{-4} to 5×10^{-4} for losses of off-site power of all durations. The comparable frequency range for blackouts longer than 2 hours is 3×10^{-5} to 1×10^{-4} For longer than 4 hours it is 1.5×10^{-5} to 5×10^{-5} (Ref. 1).

Probability of Core Damage in a Station Blackout

Calculating the probability of consequent core damage following station blackout is perhaps the most complex part of the analysis. Complete accident progression analyses, using fault trees and event trees, have been performed for key station blackout sequences, starting with the loss of off-site power through to core melt and containment failure (Ref. 1). The analyses are sensitive to reactor type (BWR, PWR) as well as design differences within reactor types. The time for recovery of AC power is another important parameter. Two time intervals seem to dominate for major categories of core damage accident sequences in which AC power must be recovered to avoid core damage. These intervals are 1 to 2 hours, and 4 to 16 hours. An assumption made is that an accident sequence that leads to core damage would likely lead to core melt. Core damage could result from core uncovery in time periods of a few hours. The estimated time between the onset of core damage and the time that a core melt would penetrate the reactor vessel is also of the order of a few hours. Possible failure of the containment building leading to a leaking of some fraction of the fission product inventory into the environment, depends on containment type and failure mode, and could occur in a time period of from a few hours to about one day (Ref. 1, pg. 7–16). Little analysis has been done to determine nuclear plant reliability during a long-term loss (> 1 week) of AC power as the studies considered mainly normal peacetime conditions.

We can summarize this section by estimating the probability of core damage as a result of station blackout in peace-time as being of the order of 0.1 per blackout event. Here, we have averaged over the variabilities due to reactor plant differences.

Conclusions of Station Blackout Program

Table 1 contains a summary of the technical results of the U.S. Nuclear Regulatory Commission's station blackout program. NUREG-1032 provides estimates of total core damage frequency. Assuming that most plants have independent emergency diesel generator (EDG) reliabilities between the required 95% and more typical 98%, have battery capacity for at least 2 hours, and can handle a loss of off-site power with one EDG, the total core damage frequency lies between 2.1×10^{-5} and 4.6×10^{-5} per reactor-year (Ref. 1, Table C.4). The total range, including conceivable outliers, is shown as 10^{-5} to 10^{-3} (see Table 1). For the purposes of this study, it is judged appropriate to use a figure of 3×10^{-5} per reactor-year.

Table 1 applies to the United States. In general, the European record on station blackout is not as good. The equivalent data for the Soviet Union is not readily available. One could conjecture however that their operating experience on station blackout is not as good as in the U.S., in part because of a less sophisticated technology. Since many of their reactors lack containment buildings, the public consequences from reactor accidents there resulting from station blackout would tend to be more severe. Chernobyl is a case in point. While the full story of the Chernobyl accident is not yet out, it appears that the initiating event was a test of the ability of a turbogenerator, *during station blackout*, to supply electrical energy for a short period until the standby diesel generators could supply emergency power.

TABLE 1

Summary of station blackout program technical results *

Parameter	Value
Operational Experience (U.S.–Peace time)	
Loss of offsite power (occurrence per year)	
Average	0.1
Range	0 to 0.4
Time to restore offsite power (hours)	
Median	0.5
90% restored	3.0
Emergency diesel generator reliability (per demand)	
Average	0.98
Range	0.9 to 1.0
Median emergency diesel generator repair time (hours)	8
Analytical Results	
Estimated range of unavailability of emergency AC power systems (per demand)	10^{-4} to 10^{-2}
Estimated range of frequency of station blackout (per year)	10^{-5} – 10^{-3}
Estimated range of frequency of core damage as a result of station blackout (per reactor-year)	10^{-6} – 10^{-4}

* From NUREG–1032 (Ref. 1) The analytical results describe the total range, including conceivable outliers.

We can use these results to estimate the frequency of core damage from station blackout, F_{CD}, from

$$F_{CD} = F_{LOP} \cdot U_{EPS} \cdot P_{CDSB} \quad (1)$$

where

F_{LOP} = frequency of loss of off-site power $\simeq 0.1$ (range 0 to 0.4) per reactor site per year,

U_{EPS} = unavailability of on-site emergency power $\simeq 3 \times 10^{-3}$ (range 1.5×10^{-3} to 5×10^{-3} for most plants)

P_{CDSB} = probability of core damage per station blackout event $\simeq 10^{-1}$ (This averages over a range of reactor incidents).

These factors combine to give for F_{CD}, the frequency of core damage, a range of 1.5×10^{-5} to 5×10^{-5} per reactor-site per year (Ref. 1, Table C.4). With approximately 100 commercial power reactors presently operating in the U.S., this analysis indicates that the expected frequency of a core damaged reactor accident in the U.S. due to station blackout is 2×10^{-3} to 5×10^{-3} per year. We will use a value of 3×10^{-3} per year as a plausible core damage frequency estimate for the sum of the 100 plants in the U.S.

We next note some important assumptions made in this analysis to estimate the probabilities of core-melt in the event of a large scale nuclear war. The data used to generate U_{EPS} (unavailability of on-site emergency power) was based on operating experience and assumed competent operating personnel were readily available and that repairs could be made in a timely fashion (average repair time for the emergency diesel generators was ~ 8 hours). The analysis that led to the estimates of core damage probabilities also assumed that reactor operating personnel were on duty in the control room and were taking intelligent actions to control the reactor until electric power was restored.

The Vulnerability of Reactors and the National Power Grid in a Nuclear War

In the event of a nuclear war, it seems likely that the national power grid would be targeted. Conventional power plants have been targeted during wars in recent decades. In the Korean war, the Yalu River hydroelectric plants serving both China and North Korea were attacked. In the 1973 Yom Kippur war, Israeli aircraft destroyed power stations in Damascus and Homs, Syria (Ref. 5). Nuclear power plants in particular represent attractive economic and industrial targets (Ref. 6).

One targeting scenario that has been proposed would involve the detonation of several nuclear weapons at altitudes of approximately four hundred kilometers over strategic locations, thereby producing an EMP (electromagnetic pulse) that could cause failures in reactors within the line of sight of such explosions (Ref. 7). An NRC study published in 1983 (Ref. 8) concluded that "peak EMP-induced signal levels at the point of interest are below the nominal operating levels and therefore no damage is expected." Reviews of this study produced a few dissenting comments. One dissenter suggested more EMP experts should have participated and that many extrapolations were made without adequate data. Another suggested that EMP could result in the temporary disruption of critical control equipment by sending false signals to operators. The NRC study authors concluded that such problems were not insuperable obstacles. The question of whether operators would be at their control stations in a war crisis was not addressed.

It is not necessary to directly attack a reactor site to damage it. *Ramberg* (Ref. 5) discussed the vulnerabilities of nuclear reactors and support facilities in some detail. A 1 megaton detonation can create overpressures sufficient to disrupt important systems such as transmission lines out to a distance of 8 km. These overpressures are also capable of damaging intake air filters for emergency diesel generators, restricting air flow so that they could not operate, possibly resulting in core damage and a probable meltdown. At 3.7 km, the explosion could damage the transformers that provide power for plant operation.

At 2.5 km, damage to the containment building would impair systems designed for steam suppression. The primary coolant loop might suffer some damage. At 0.8 km, the containment building could be breached, and the primary coolant system could be ruptured causing depressurization of the primary system. At 0.6 to 0.7 km, the radioactive core inventory could be entrained into the weapon s rising plume (Ref. 5, Chapter 2).

Sabotage and well-placed conventional weapons can also easily cause disruptions in a power grid and individual reactors. There have been numerous examples of this, the most recent occurring on May 14, 1986 when three of the four high voltage lines through which offsite power can reach the Palo Verde reactor complex were sabotaged and knocked out (Ref. 9). Conventional explosives, rockets and artillery are becoming more powerful and more accurate. These potential "non-nuclear" threats have produced proposals to provide control rooms with "bunker" protection, but this would probably involve a severely inhibiting expense.

In summary, power grids and nuclear power facilities are vulnerable in times of war. We can assume that the system national power grids will be targeted and out of action for an extended period (of the order of weeks or longer). Since station blackout events resulting in core damage manifest in a time frame of 1 to 16 hours and the critical period when electric power is needed for reactor control and cooling to prevent core damage is of the order of 1 or 2 weeks, we can assume for the purposes of this report that the off-site power will be lost indefinitely.

Core Damage Estimates Following a Nuclear War

Here we examine how our analysis of the "peace-time" station blackout problem would be modified in a war-time situation. Equation (1) for calculating F_{CD}, the frequency of core damage from station blackout, contains the factor F_{LOP} (frequency of loss of off-site power). Instead of a F_{LOP} value of 0.1 per reactor-site per year, we shall use a figure of 1 for war-time conditions. This assumes all of the power grids in the U.S. will be down for an extended period.

For U_{EPS}, the term that describes the unavailablity of on-site emergency power in the equation, an important consideration is the supply of diesel fuel available on-site for operating the emergency generators. Recent standards on most reactors require a seven day supply of diesel fuel to run the generator. The diesel fuel supply would be adequate for longer periods. If additional deliveries of fuel to the reactor site are possible. (Ref. 10). Of course, direct damage to the emergency generators and lack of repair support could cause U_{EPS} to approach unity. Hence we shall use values of U_{EPS} that range from the peace-time value of about 3×10^{-3} to a more pessimistic "war-time" value of about 0.3. While this latter upper estimate is arbitrarily established, our central conclusion is not highly sensitive to its value.

For the term P_{CDSB} (probability of core damage following station blackout), we shall use the peace-time value of $\simeq 0.1$ as a lower limit, which averages over many reactors and accident sequences, and which assumes that the reactor operators and control room facilities are functioning normally. We will somewhat arbitrarily assume a higher value of 0.5 for more pessimistic war-time conditions.

Using the above values for the factors in equation (1), we can calculate some rough estimates for the frequency of core damage in the event of nuclear war. Using the more optimistic figures, in which only the probability of the loss of off-site power is changed, we obtain

$$F_{CD} = (F_{LOP})\ (U_{EPS})\ (P_{CDSB})$$

$$= (1)(3 \times 10^{-3})(10^{-1})$$

$$= 3\times10^{-4} \text{ per reactor} - \text{site}$$

Hence, a lower limit probability of a core damage—release incident in the 100 operating reactors in the USA from station blackout in the event of war is about 3×10^{-2}; a factor of 10 greater than the peace-time value reported earlier. Using the more pessimistic assumptions involving direct damage to reactors, we can arrive at a rough estimate of the frequency of core damage.

$$F_{CD} = (1)\ (0.3)\ (0.5) = 0.15 \text{ per reactor} - \text{site}$$

Hence a more pessimistic rough determination of the number of release incidents from station blackout in the 100 U.S. reactors in the event of a nuclear war is about 15. This latter figure depends on parameters that are highy scenario dependent (how many reactors are damaged, how many are operating and manned, etc.).

Radiological Implications of Reactor Releases Compared with Nuclear Weapon Detonations

In this section we address the radiological implications of our estimates of major reactor releases and compare them with those from nuclear weapon detonations.

There exists considerable literature on the analysis of the potential radiological consequences of reactor accidents as well as a few actual incidents to examine (TMI, Windscale, and Chernobyl). There are many variables in this problem, and we shall seek here order of magnitude estimates.

Baranowsky reports on probable population exposures of from 2 to 5 million person-rems (to 80 km.) for varying containment fission product release categories and failure mode probabilities for various station blackout sequences (Ref. 1, pgs. 7–19). Beyea gives estimates of early deaths to be expected in a major release from a PWR (pressurized water reactor). By considering many hypothetical accidents with varying weather conditions, relocation strategies, and medical treatment availabilities, figures for early deaths range from a few hundred up to 10,000 in an extreme case. Beyea also estimates population exposure and long-term fatal cancers at all distances from 3 major release categories involving a BWR at Barseback, Sweden. He concludes that total fatal cancers would range up to 16,000 (Ref. 11). A similar analysis involving *hypothetical* accidents at Three Mile Island (TMI) produced estimates for the most serious accident designation of from 550 to 60,000 delayed cancer deaths. The actual releases from the 1979 TMI accident were microscopic compared to these hypothetical accidents.

Chernobyl provides the worst example of a reactor accident. While final figures are not yet available, early deaths appear to be about 30 with an additional 203 cases of acute radiation sickness. All of these cases were individuals who were on-site workers or fire fighters. None of the general population off-site received exposures large enough to cause observable acute radiation sickness. Distances of serious contamination (requiring evacuation) extended out to tens of kilometers. Von Hippel and Cochran used dose projections for Chernobyl calculated by the Atmospheric Release Advisory Capability (ARAC) Center at Lawrence Livermore National Laboratory to arrive at estimates of 2,000 long-term deaths from cancers and leukemia arising from a projected total population dose of 7×10^6 person-rems from external whole body exposure to gammas from the radioactive cesiums (Ref. 12). Two thousand cancer deaths among an exposed population of 100 million in Eastern Europe would raise the risk of cancer death of the average person there by only .01 percent, e.g., from 20 percent to 20.002 percent. The extra cancer deaths predicted from Chernobyl will therefore be lost among the cancer deaths that would have occurred from current and natural causes. Estimates of thyroid nodules induced by iodine-131 (mostly benign) range in the many tens of thousands. The ARAC calculations estimated that the source term for the Chernobyl release for iodine-131 was 36 million curies. This compares with 20 thousand curies for the Windscale accident, and 20 curies for TMI-2. The relevant estimates for cesium-137 were from 2.4 million curies for Chernobyl, 1000 curies for Windscale, and none detected for TMI (Ref. 13). The ARAC source term estimates were based on measurements outside of the Soviet Union. The Soviet estimates were somewhat smaller, and were based on measurements within the Soviet Union.

Based on new Soviet data presented at an IAEA conference on Chernobyl in Vienna in August, 1986, preliminary estimates were made of an additional 21,000 long-term cancer deaths due to internal irradiation from cesium 137 injested through the food chain. Most of these predicted additional cancers would occur amongst the populations of the Soviet Ukraine and Byelorussia regions (Ref. 14). These more recent estimates of latent effects are however in dispute by others.

Considering the design of the Chernobyl reactor, the violent explosion, the almost complete destruction of the building opening up the reactor core to the atmosphere, the ensuing fire and continuing releases spread out over days, and the apparent release into the atmosphere of a significant share of the fission product invectory, one can conjecture that the Chernobyl accident represents an example that would lie closer to a "worst case" accident scenario compared to the kinds of recent hypothetical accident studies sponsored by the Nuclear Regulatory Commission and the IDCOR nuclear industry group. A major mitigating factor for U.S. reactors is the efficacy of the containment structure present on all commercial plants. These containments can greatly diminish the public exposures due to a core melt, as was the case at Three Mile Island.

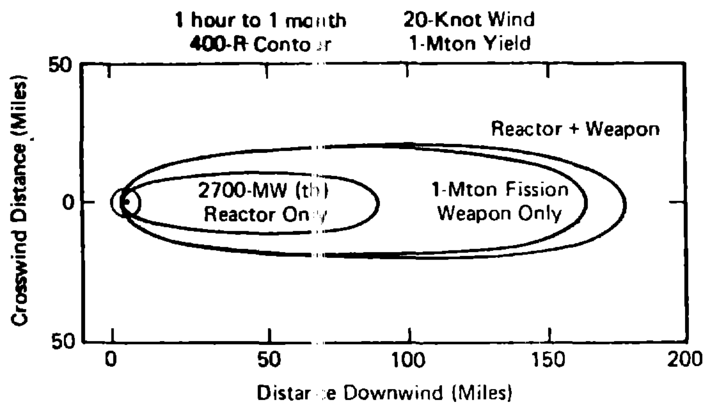
Fetter and Tsipis (Ref. 15) have compared the radiological consequences of nuclear explosions to those of a major reactor release from both a melt-down incident as well as from the direct targeting of a reactor core and its subsequent dispersal by the weapon explosion. They conclude that the radiological doses from a 1 megaton weapon would completely overwhelm that of a major reactor release alone (the situation discussed above). When a nuclear reactor is targeted with a nuclear weapon, the areal extent of contamination from the reactor radioactivity inventory is greatly increased. Figure 1, taken from *Chester and Chester* (Ref. 16), illustrates that the radiation isodose contours for a weapon in the early weeks after detonation are much greater than those for a major reactor release. In the long term (months to decades), the reactor radioactivity dispersed by the weapon dominates because of the reactor's richer mix of long-lived radionuclides. This is illustrated in Figure 2 which compares the long-term denial of land to survivors from (a) a grave reactor accident, (b) a 1 megaton weapon ground burst, and (c) detonation of the weapon on a reactor (Ref. 15). Note that the dose rate levels considered in Figure 2 are below those that would produce acute radiation sickness, but would add to the long-term incidence of cancer, leukemia, and genetic mutations.

To quote ***Fetter & Tsipis***, "The gravest conceivable accident to a nuclear reactor is far less destructive than the detonation of a nuclear weapon, even if it is imagined that the weapon causes harm only by radiation." A ground burst of an assumed one megaton all fission nuclear weapon can produce a 48 hour unshielded dose of 450 rads on an area of about 1000 km^2 (Ref. 17). This dwarfs the equivalent area for a major reactor release (for Chernobyl this has been estimated at less than 10 km^2 (Ref. 18).

Recent projections of scenarios for a major nuclear war have assumed the detonations of 5 to 6 thousand megatons total yield from 10 to 12 thousand warheads from the U.S. and Soviet strategic nuclear stockpiles (Refs. 19, 20). The U.S. might be targeted with aproximately half of these. Fallout calculations carried out by our group at Livermore have produced estimates of early deaths in the U.S.A. from local (early) fallout that ranged from about 1 million to 20 million, depending sensitively on the choice of scenario. These figures are obtained after early deaths caused by the direct effects of blast and fire are subtracted from the total of early deaths of some 100 to 150 million people.

Global fallout calculations for the above major strategic exchanges have projected global population exposures (50-year doses from external gamma exposures) of about 5 $\times$ 10^{10} person-rads (about 4 orders of magnitude more than a Chernobyl-type accident). About one tenth of this would be in the U.S. (Ref. 17). The biological effectiveness of irradiation that is extended in time (chronic dose) is far less than that of a short term (acute) dose because of the human capacity for biological repair of radiation damage. (Ref. 20).

In summary, the short term radiation from many nuclear weapon detonations is potentially far more destructive than that from a number of major reactor releases.



The 400-R isodose contours for one hour to one week for fallout from a 1000-MW(e) reactor, 1-Mton fission weapon, and combination.

Figure 1 1,000 MW(e) LMFBR and 1-Mton Fission Weapon Contours. From Chester and Chester (Ref. 15)

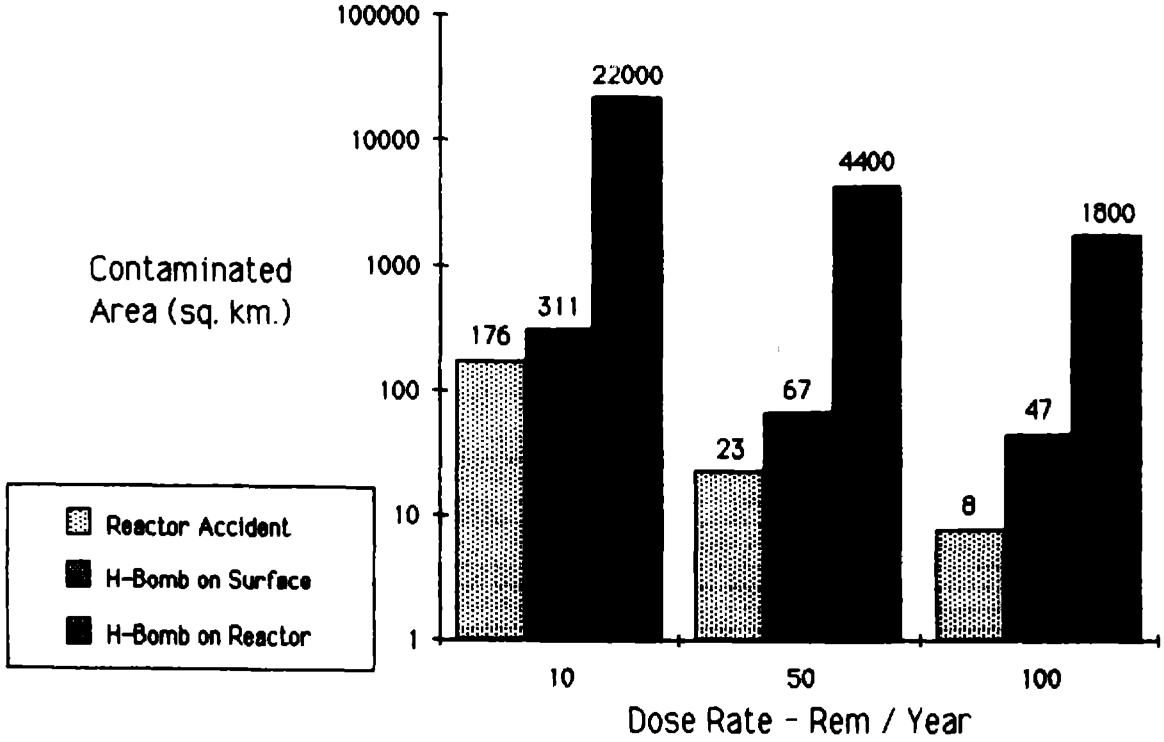


Figure 2 From Fetter and Tsipis, (Ref. 14) DENIAL OF LAND to the survivors of a release of radioactivity depends on the dose of radiation the survivors would be willing (or compelled) to absorb. Presumably a dose rate of even a few rem per year would be intolerable after a peacetime accident, whereas the survivors of a nuclear attack might attempt to endure far more. The bars show the amount of land that must remain uninhabited for a year if the maximum acceptable dose rate is 10 rem per year *(left)*; 50 rem per year *(middle)* or 100 rem per year *(right)*. Again three possible sources of radioactive contamination are considered: a grave reactor accident *(light color)*, the ground-level detonation of a thermonuclear weapon *(medium color)* and the detonation of a thermonuclear weapon on a reactor *(dark color)*. If more than 10 rem per year is unacceptable, the amount of land that must remain uninhabited for a year after the attack on the reactor is 22,000 square kilometers.

Conclusions: Implications of Station Blackout From Nuclear War

In previous sections, we have seen that recent work on "peace-time" station blackout have produced estimates for the probability of a major core damage-reactor release accident in the U.S. to be about 3×10^{-3} per year. For the war-time situation where we assume that off-site power is unavailable indefinitely, but that the reactors and their personnel are unaffected by the war, the probability of a major reactor release in the U.S. from station blackout is increased tenfold to 3×10^{-2}. This is still a rather small value. If we use more pessimistic assumptions in a nuclear war, our estimates imply about 15 major station blackout related release incidents out of the 100 reactors currently operating in the U.S. We have also seen that the detonation of a single megaton-sized nuclear weapon has far more serious short term radiological consequences than that of a major reactor core release. In the long term (months to years), the reactor contributed radiation will dominate, but the main effect to most of the surviving population of these long-term dose rate levels would be to add to the long-term incidence of cancer, leukemia, and genetic mutations.

When one considers that typical war scenarios for a major exchange assume the detonation of some thousands of warheads in the USA, we reach the conclusion that the station blackout radiological problem in a nuclear war situation will be completely over-shadowed by the radioactive contamination from the weapons. While a reactor accident (a la Chernobyl) is a major catastrophe in peacetime, it pales relative to the casualties expected in a major nuclear war. Even the normally horrific radiological implications of 15 simultaneous Chernobyl-type accidents would be small compared to those of a major nuclear exchange.

In the above, we have compared for the United States the radiological releases of station-blackout reactor accidents in peacetime conditions with those from a major nuclear war. A possible intermediate scenario could involve a small number of nuclear weapons or even a non-nuclear attack by organized military forces or saboteurs. In such events, the radiation from 15 Chernobyl's would no longer be dominated by the releases of radiation from nuclear weapons. With the continued development of more sophisticated and accurate weapons, both conventional and nuclear, and the general world-wide rise in the level of terrorism, there are many who believe an intermediate scenario could become more likely in time.

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